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Space Research

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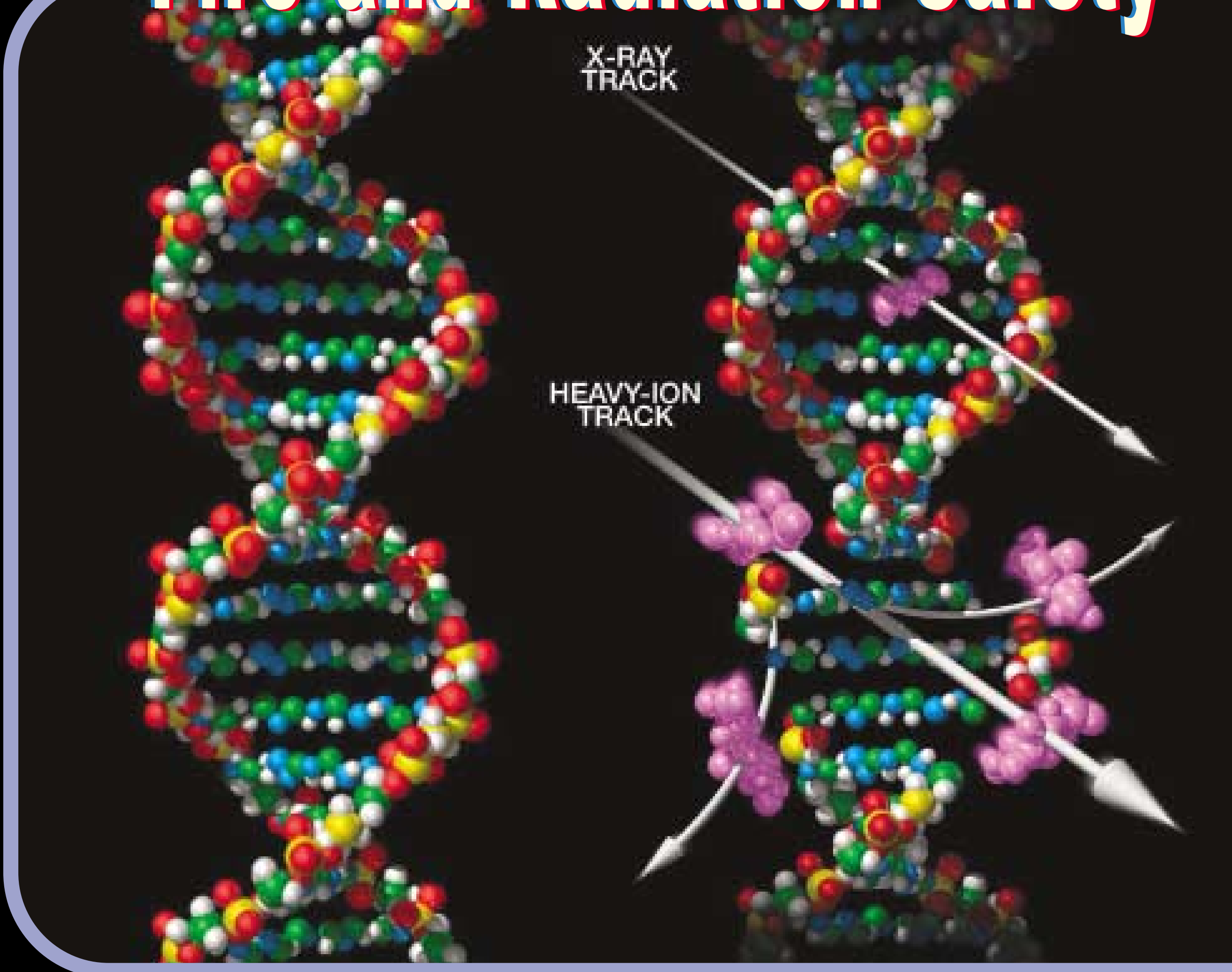
Fire and Radiation Safety



Profile:
Peggy
Whitson

National Aeronautics and
Space Administration

Fire and Radiation Safety Get New Emphasis From

NASA's mission success starts with safety.

Credit: U.S.Navy photo by Photographer's Mate 1st class Michael Worner.

A Navy fire-fighting instructor leads firefighters in battling a Class Bravo (oil-fed) fire during a military training session. Both NASA and the military put great emphasis on being prepared for various fire hazards, either on Earth or in space.

As crews from the United States and its partners assemble the International Space Station (ISS), the casual observer may miss an underlying emphasis on safety that makes the work sometimes appear effortless.

"Safety is NASA's number-one core value," says Kristen Erickson, deputy associate administrator for management in the Office of Biological and Physical Research (OBPR), NASA's newest enterprise. "One of the things we are trying to instill is that safety has to be a state of mind. You can't just put up a bunch of posters." Erickson previously was head of the space shuttle's budget office and program evaluation, where flight safety had the highest importance, "so you can see why I'm such a zealot," she explains.

While the general public may be concerned about safety in space only after an accident or a catastrophe, NASA has ongoing commitments to ensure that vital equipment does not fail on the ground or in flight and to reduce occupational hazards for ground and flight crews. Supporting research on in-orbit fire prevention, detection, and extinction and on the effects of space radiation and shielding is one way NASA meets these commitments. Fire and radiation safety are linked by a common need: to further our understanding of basic science and use it to develop advanced materials. Fire is a violent chemical reaction, as oxygen combines with other materials to produce smoke, heat, and deadly chemicals. Radiation involves high-energy particles (as well as X-rays and gamma rays) that can have devastating, even deadly, effects on living beings. NASA wants to apply the results of research in basic and applied science to reduce the hazards from each. But first, scientists must understand and fully define the fire and radiation problems, and then they must tackle new designs to mitigate or eliminate them. OBPR will play a key role in doing both.

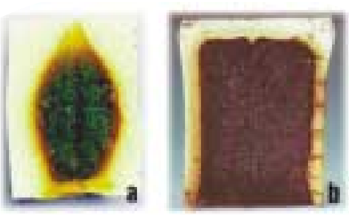
"One thing we expect to invest further in is research on space radiation and its potential impact on humans," Erickson continues. She also expects that in addition to making space travel safer, the fire and radiation studies will find beneficial applications on Earth.

Fire

Until recently, most of OBPR's interest in fire was in using microgravity as a research lab for insight that might improve combustion systems on Earth. While this remains a highly valuable line of work, OBPR has new emphases on studying how fires start and propagate in microgravity and how they can be extinguished quickly and safely. The subject is far more complex and subtle than campers pouring water on the fire until the flames and sparks disappear.

To grapple with the challenge, NASA held a workshop dedicated solely to spacecraft flammability issues at Glenn Research Center (GRC), NASA's lead center for microgravity combustion research, in June 2001. Participants at this first workshop of its kind in 15 years included representatives from the National Institute of Standards and Technology, the Naval Research Laboratory, Sandia National Laboratories, and universities, as well as from NASA. Attendees addressed fire prevention and materials flammability, smoke and fire detection, and fire and postfire response. "We wanted to assess the state of the art of spacecraft fire safety, determine the knowns and unknowns, and identify specific research needs," said Gary Ruff, of GRC, who chaired the workshop.

The first, most important step that can be taken, whenever possible, in fire safety is to select materials that don't burn easily in low gravity. NASA's Marshall Space Flight Center has a Materials Combustion Research Facility that tests materials against a range of industry and NASA standards. Because it is impossible to eliminate all combustible materials, such as the paper on which flight plans and procedures are written or the plastics that are used in almost everything, steps also must be taken to ensure that a fire can be detected and extinguished while protecting the crew and equipment. ISS

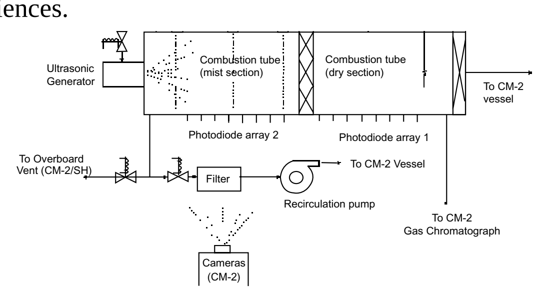


credit: NASA

Research has shown that the way a material such as polyurethane foam burns in regular gravity and air (a) is no indication of how it will react in microgravity and an atmosphere of enriched oxygen (b).

fire detectors, developed through experiments sponsored by OBPR's Physical Sciences Division and conducted on the shuttle, look for smoke particles sparkling in a laser beam. To fight fires, the crew is supplied with portable fire extinguishers (which dispense carbon dioxide) and portable breathing apparatus. NASA wants a nontoxic suppressant that does not foul the life support system or require extensive cleanup. The workshop recommended conducting microgravity experiments, in addition to continuing those in ground-based facilities, on items likely to burn in space. Research is also needed in computational flow dynamics to understand where a fire goes inside a compartment in microgravity, how fire-fighting agents are transported, and how the agents interact with the air and fuel.

"One thing that came out of the workshop was a new roadmap for spacecraft fire safety research," Ruff says. "After the workshop, we revisited our existing research projects and plans to make sure we didn't miss anything and shift some priorities. It really helped us define and focus our current research better." The results of the workshop are refocusing existing projects and will affect future NASA Research Announcements (NRAs) with regard to combustion sciences.



Credit: Colorado School of Mines.

A schematic diagram of the apparatus for the Water Mist project.

In the past, several shuttle missions carried experiments to examine the microscale physics and chemistry of combustion under low-gravity conditions, where convective flow is nearly eliminated, clarifying the view of what is happening. The ISS is expected to host a broader range of combustion experiments over the next 10 to 15 years. Attention now is shifting to understanding the physics and chemistry of putting out fires for applications on Earth as well as in orbit. The space shuttle's Research-1 mission (STS-107, scheduled for launch in 2002) will take the first step in this new direction with the Water Mist experiment.

"We are trying to understand the fundamentals," says Frank Schowengerdt, director of the Center for Commercial Applications of Combustion in Space (CCACS), a NASA commercial space center located at the Colorado School of Mines. "We want to understand how fire extinction depends on water particle size, water concentration, droplet distribution, and radiation from the fire." The CCACS is part of OBPR's Space Product Development program. Water Mist is a different approach for the center, since the CCACS was established to develop improved combustion technologies, not to study how to stop fires.

"When we first set up this center, Tom [McKinnon, a CCACS chemical engineer,] said he had always puzzled over just exactly how water puts out a fire," says Schowengerdt. "Five years ago, he wasn't taken seriously. Another federal agency said they did some research three to four years ago and gave up. But they did it the wrong way, through crude trial and error." McKinnon persisted and developed more analytical experiments and models. He is now the principal investigator for Water Mist. "Without doing the fundamental science you don't make advances," Schowengerdt continues. "You

Credit: CCACS

This sequence of photos shows a standard fire suppression test of the EEC Water Mist System at the Fire Training and Research Center in Arvada, Colorado. A clearly visible cloud of mist descends over the flames, putting out the fire quickly and efficiently. The effects of different water droplet sizes and concentrations are tested to determine the optimal parameters of the system.

might get lucky in a trial-and-error approach, but you might spend a lot of money on it."

Schowengerdt and his colleagues want to know the absolute minimum required to put a fire out so the cleanup is easier, postfire damage is reduced, and flight crews are exposed to fewer toxic by-products. Scientists are returning to water as the ideal suppressant.

Water droplets have more surface area than a stream of the same volume straight out of a hose. Droplets can absorb more heat and coat more fuel. But exact details of the physics and chemistry remain elusive, largely because the reactions happen so quickly in Earth's gravity. Droplets settle, so a controlled, uniform cloud of them can't be maintained to see what happens when the flame interacts with them. In microgravity, the drops remain suspended, so a better experiment can be conducted. Therefore, McKinnon looked to orbit, where experiments can run slower and with less turbulence. Scientists can thus focus on a narrower range of variables and study them over an extended period of time.

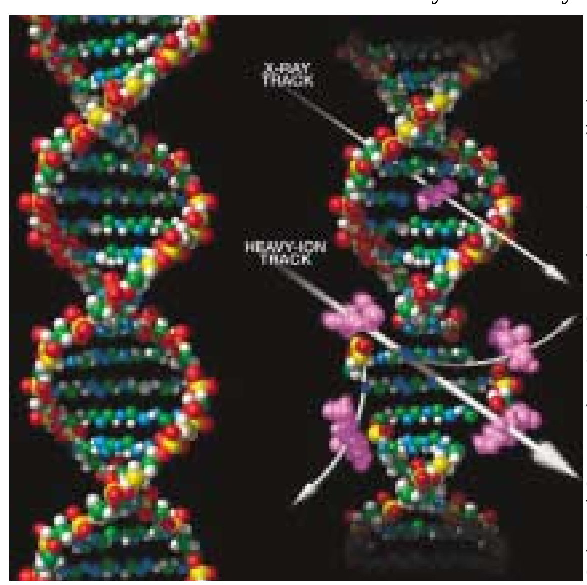
The CCACS has conducted extensive tests on the ground, including some at a drop tower facility at the School of Mines. Now it is time to move upward, literally. "We're looking at a lot of different things that we can do far better in microgravity," Schowengerdt explains.

Water Mist will employ a small nozzle to spray water into a chamber through which the flame will move. "We're not talking here about sprinkler systems that everyone has," Schowengerdt says. Because a high-pressure water line would be difficult to set up in the confines of the experiment module, ultrasonics break the water into droplets about 10 microns in diameter. "You probably couldn't use that in a real situation, because high pressures are needed," says Schowengerdt. For fundamental experiments, though, the mist should be sufficient. From this, scientists could start to develop methods to optimize water sprays for different types of fires. The CCACS also is looking at additives that would keep the water from conducting electricity. Following STS-107, Schowengerdt hopes to do extended experiments aboard the ISS.

The CCACS's work is getting attention from potential terrestrial users, including the Federal Aviation Administration, the U.S. Navy, computer system operators, and even restaurants. NASA also is interested in Water Mist as part of a larger investigation into fire safety aboard spacecraft.

Radiation

The latest NRA is looking at protection from one of the earliest-known space hazards. Radiation brings a different set of complexities and subtleties to the problem of protecting crews. "Empty" space is heavily traveled by radiation that can sicken or kill any known life-form. While ISS crews are relatively shielded by



Credit: Frank Cucinotta, Johnson Space Center, and Prem Saganti, Lockheed Martin

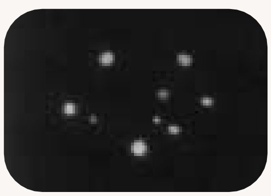
The blueprint of life, DNA's double helix (left), is found in the cells of everything from bacteria to astronauts. Exposure to radiation (right) can change or disrupt the polymer strands of nucleotides joined together, causing dire consequences both to the organism itself and to its future generations.

Fire in Space

The extreme reduction of buoyancy in the microgravity environment of orbit means a fire's hot products no longer rise, and cold air no longer sweeps in to take their place, thus sharply reducing the magnitude of the fire. The image of a space candle surrounded by a ghostly blue sphere as exhaust products diffuse outward and fresh oxygen diffuses inward is the best-known result of a long series of space combustion experiments conducted aboard U.S. space shuttles and Russia's *Mir* space station. Such studies promise to let scientists and engineers fine-tune the design of engines so that they burn fuel more efficiently and produce fewer toxic by-products.

Several discoveries about the physics of combustion have been made in recent NASA experiments. The Fiber-Supported Droplet Combustion experiment on the Microgravity Science Laboratory-1 (MSL–1) showed two droplets pushed apart by their exhaust gases, then drawn together as oxygen was depleted between the drops and combustion faded on the facing sides of the droplets.

Also on MSL–1, the Structure of Flame Balls at Low Lewis-number (SOFBALL), investigated small fireballs that form when a spark arcs through a lean fuel-air mixture. Although they are the weakest known flames (only 1 watt thermal), they usually lasted for minutes, often longer than the experiment runtime. The implication for fire safety is that fuel gases in a spacecraft could be ignited and drift across a cabin, undetected, for several minutes. Space testing of some materials, such as plastics widely used in flight hardware, has started, as described in "Flammability Results from *Mir*," in the Spring 2000 issue of *Microgravity News* and "Revolution in the Making," in the Winter 1998 issue.

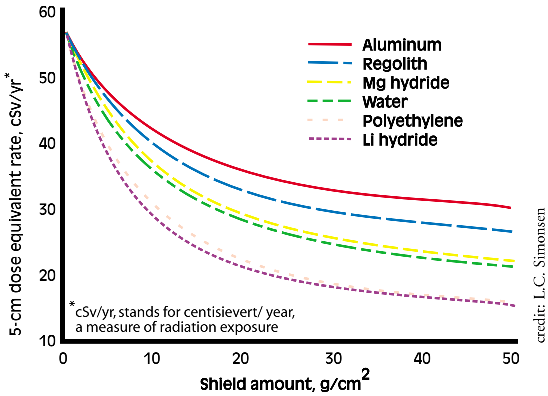


credit: NASA

The Structure of Flame Balls at Low Lewis-number (SOFBALL) investigates small fireballs that can ignite in the lean fuel-air mixture inside spacecraft. While weak (1 watt versus 50 watts for a birthday candle), they can last for several minutes and are very difficult to detect. The fireballs in the picture are visible only because they were captured in the dark by cameras with image intensifiers.

Earth's magnetosphere, they are more exposed than people living at sea level beneath Earth's cushion of air. Crews that travel to Mars will be exposed far longer than the Apollo crews going to the Moon — years instead of days. The agency also wants radiation issues addressed openly by managers and astronauts alike: "We are very much concerned that the acceptance of risk is an important ethical issue that gets revisited continuously," Erickson says.

Like fire safety in space, OBPR is working simultaneously to define the problem in full even as it works on possible solutions. Its Strategic Program Plan for Space Radiation Research outlines a comprehensive approach to develop these solutions. In addition, NASA works closely with the National Research Council of the National Academy of Sciences and with the National Council on Radiation Protection and Measurements to maintain updated guidelines from the scientific and radiation protection communities.



Materials with smaller mean atomic mass, such as lithium (Li) hydride, make the best shields for astronauts. The materials have a higher density of nuclei and are better able to block incoming radiation. Also, they tend to produce fewer and less dangerous secondary particles after impact with incoming radiation.

From an enterprise perspective, radiation protection is truly a cross-disciplinary, cross-division problem that touches life sciences, space biology, and the physical sciences. To systematically study the biological effects of space radiation, NASA has been developing a new ground-based space radiation simulation facility, the Booster Applications Facility. The facility, which is expected to be commissioned in 2003, is being built in collaboration with the Department of Energy and will utilize high-energy accelerators at Brookhaven National Laboratory. When the facility is fully operational, atoms of various elements will be stripped of their electrons and accelerated to high velocity to produce the full range of particles and energies that are present in space.

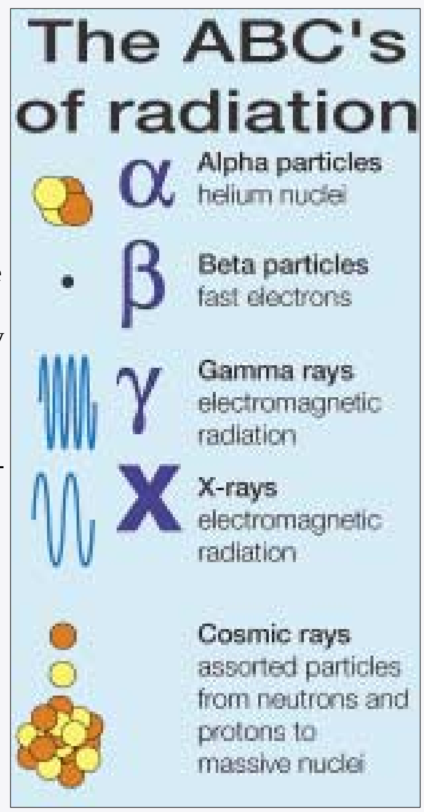
Ground-based studies in already-existing facilities have shown that the effects of space radiation are significantly different from the effects of X-rays and other radiation types common on Earth. The high-energy charged particles of space radiation, threading through a coiled DNA molecule, can easily break it in more than one place. A study of the size of the broken pieces has led to a new understanding of how DNA

The ABCs — and Xs and Zs — of Radiation

Alpha and beta rays are particles. Gamma rays are electromagnetic radiation, like X-rays but at higher energies. Health physicists worry most about HZE cosmic rays, those with high mass (Z stands for atomic number, which also implies mass) and energy (E). They have two principal sources, the Sun and the galaxy.

Solar Energetic Particles (SEPs) are largely high-energy protons, naked hydrogen nuclei. Radiation from a solar flare can be debilitating or even fatal in an unshielded exposure. Galactic cosmic rays (GCRs) come in a wide variety of naked atomic nuclei spewed from supernovas or from dust pummeled by older cosmic rays. Most are made of lightweight stuff, about 85 percent hydrogen (Z=1) and 14 percent helium (Z=2) nuclei. The remaining 1 percent are mostly heavier, stable elements. The heaviest element that is sufficiently abundant to be of concern for radiation protection is iron (mass around 56), although traces of all stable elements have been observed in GCRs. The median velocity of the GCRs is approximately 95 percent of the speed of light (corresponding to the velocity of a proton with an energy of 2000 MeV). The radiation content changes with the solar cycle. At sunspot maximum, the expanded heliosphere moderates GCRs, but emits more SEPs.

Like a bullet fired through a cinderblock wall, a cosmic ray hitting metal shatters the target nucleus and is itself shattered. Although the total energy remains the same, the interaction showers secondary and tertiary particles, some of which produce gamma rays. All in all, it is a messy business.



winds itself up for storage in the cell. Another way in which space radiation can be seen to be different is by enhanced "genomic instability," a result of irradiating living cells that leads some of the dividing daughter cells, as many as 10 or 20 divisions later, to change in the direction of becoming cancer cells, at a rate much greater than the control cells.

Because of these and other dangers to human space travelers, radiation in space must be avoided as much as possible. At present, exposure to radiation is reduced in one of two ways: the use of "shielding" materials interposed between humans and the external radiation to attenuate its intensity, and careful timing of space activities to coincide with times when radiation is least intense.

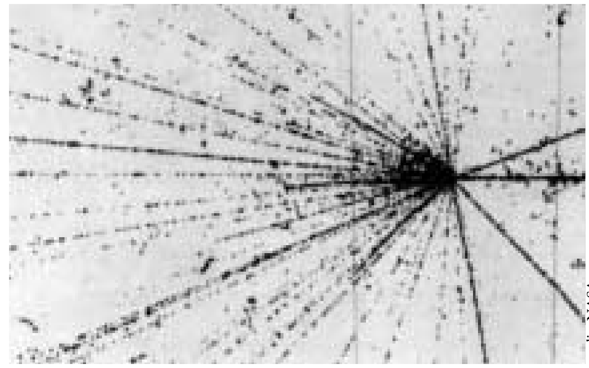
To build a better shield, NASA must understand fully what happens when radiation strikes different materials, including flesh. (See sidebar titled "The ABCs — and Xs and Zs — of Radiation.") "We need to know the interaction with a spacecraft and its shields, and also what happens after particles get through something," says Michael Wargo, materials science discipline scientist of OBPR's Physical Sciences Division. "Materials science is responsible for [addressing] one part of the problem. We are approaching on two fronts. We need models and computer programs to predict. And we need experiments to validate and to improve models and programs."

A workshop at Lawrence Berkeley National Laboratory (LBNL) in 2000 developed a roadmap to plan a tractable solution to the problem. Its findings are incorporated in "Materials Science: Ground-Based Research Opportunities in Biomaterials and Radiation Shielding" (NRA-01-OBPR-05), released August 24, 2001.

"There are three things we need to know," says Walter Schimmerling, of NASA headquarters, who developed the strategic plan and is a principal author of the roadmap. "First, we need to be able to predict the risks, like possible health effects, that are likely to occur and the percentage of the time that they will occur. Second, we must reduce the uncertainty of risk. We need precise predictions. Third, we have to moderate the risk."

Radiation protection will involve a series of steps, not a single solution. "One way [to limit the risk of effects from radiation] is by timing the exposure," explains Schimmerling. For example, extravehicular activity is scheduled to avoid passages through the South Atlantic Anomaly, a low-altitude portion of the Van Allen Radiation Belts over the coast of Brazil, where radiation is more prevalent than in other sections of Earth orbit.

"Next, you can reduce the amount of radiation that gets to people," Schimmerling continues. That



credit: NASA

Certain types of radiation are dangerous to the body because they collide into cells with an effect similar to the above image of a debris trail left by an iron nucleus slamming through plastic. The impact breaks up the incident particle into smaller particles that can then penetrate and damage the cell and surrounding tissue.

means introducing materials that interpose their atoms between the crew and the outside. Atoms are largely empty space, with electrons spinning around a nucleus like remote planets circling a sun. Incoming cosmic rays will be slowed down by friction with the electrons and, every once in a while, they may hit a nucleus, although there is plenty of room for cosmic rays to miss "solid" matter.

Ideally, one would like all the incoming cosmic rays to lose so much energy in the shielding material that they stop inside of it. Unfortunately, the amount of material required to stop the lightest and fastest particles — their "range" — requires an amount of material much greater than anything that can be carried on a spacecraft. In addition, the heavier cosmic rays that do collide tend to break up into lighter pieces with the same velocity and, therefore, with greater "range."

Still, biologically, slowing down some types of cosmic rays makes them more damaging, so it is preferable to have these collisions. Conversely, slowing down the heaviest cosmic rays sometimes results in less biological damage. Thus, the evaluation of shielding effectiveness is a complex issue that depends very much on the actual composition of the radiation. Schimmerling credits NASA's Langley Research Center for work in the late 1980s on radiation transport calculations that showed that materials that contain a high proportion of hydrogen make the best shields. One of the most practical materials is polyethylene, a polymer chain of carbon atoms, each connected to two hydrogen atoms — the stuff plastic grocery bags and kitchen cutting boards are made of.

The most important areas of a spacecraft to shield are the crew quarters, galley, and other areas where the crew spends a third or more of their time. (See sidebar titled "The Christmas Radiation Brick.") "But you can't block everything," Schimmerling continues. "After 40 or 50 percent you reach the point of diminishing returns." If a thickness of shielding reduces radiation intensity by one-half, adding the same amount only reduces the remaining radiation by one-half of one-half, or one-fourth. The third layer only contributes one-eighth the protection, and so on. Therefore, the next level of protection is to understand what happens at the biological level when radiation passes through a cell and determine how to help the body's natural repair systems. "In the long run, we are trying to provide some biomedical intervention," Schimmerling says.

"Complicating the exposure issue is the fact that not all people react equally to the same dosage," says Francis Cucinotta, of Johnson Space Center's Life Sciences Directorate. "Younger people are more susceptible to damage because they have more years left for damage to develop, and their cells are still more actively dividing to replace themselves. Women are at greater risk for radiation-induced cancer because they have two radiation-sensitive organs (breasts and ovaries), and a longer expected lifespan."

As the revolution in the understanding of biology continues, it is clear that, eventually, ways will be found to improve the ability of damaged cells in human bodies to repair themselves, to help the body to rid itself of cells too damaged to be repaired, to understand the differences between individuals that make some less resistant to radiation than others, and to develop tools to diagnose changes, such as the ones that lead to cancer, much earlier, when the chances of successful treatment are vastly better.

In the meantime, quantifying the risks and actual exposures better will allow NASA managers to determine how many missions an individual can safely make. "What we would like to do in clear terms is be able to assess within an appropriate margin of safety, so every astronaut can have three 180-day missions on the ISS," Schimmerling says. That level could be achieved by older males now, but NASA wants to be able to offer equal mission opportunities to all astronauts. In addition to the all-important safety of NASA crews, being able to assure longer, multiple missions can help NASA realize substantial savings by allowing for the scheduling of fewer crew replacement missions and limiting the size of the astronaut corps that needs to be maintained. Career limits are also likely to be an important issue for astronauts, whose hard-won experience cannot currently be utilized for more than one or two ISS missions.

Schimmerling expects that the current revolution in biology will allow significant advances. "Can you give people a medicine to inspect and repair cells?" he asks. "There are mechanisms in the body that do this already. We just don't know how they work or how to harness them to undo radiation damage." But given time and research — radiobiology research in the Bioastronautics Research Division and materials research in the Physical Sciences Division — OBPR scientists hope to find the answer.

Dave Dooling

For more information on fire safety research in space, look up *http://microgravity.grc.nasa.gov/combustion/index.htm#top*. A copy of "Materials Science: Ground-Based Research Opportunities in Biomaterials and Radiation Shielding" (NRA-01-OBPR-05), which includes the roadmap to solving space radiation problems, is available at *http://research.hq.nasa.gov/ code_u/nra/current/NRA-01-OBPR-05/ index.html*. Questions for Gary Ruff should be directed to *Gary.A.Ruff@grc.nasa.gov*; for Michael Wargo, *michael@microgravity. msad.hq.nasa.gov*; for Walter Schimmerling, *wschimme@mail.hq.nasa.gov*; for Francis Cucinotta, *francis.a.cucinotta1@jsc.nasa.gov*. For more information on the CCACS, go to *http://www.mines.edu/research/CCACS/*.

The Christmas Radiation Brick

While most kids try to avoid getting a lump of coal in their Christmas stockings, astronaut Susan Helms, a member of the ISS Increment 2 crew, got a brick. This was the Christmas Radiation Brick, a truly American gift, devised by an engineer in his garage applying the results of 20 years of research into nuclear physics and shielding calculations for actual shielding use. The results of this work predicted that one of the best shielding materials would be polyethylene.

Francis Cucinotta, of Johnson Space Center's (JSC's) Life Sciences Directorate, credits JSC's Mark McDaniel with developing a quick, effective way to give Helms extra shielding in her temporary sleep station. "In his garage, he came up with this concept of blocks," explains Cucinotta. "It's just polyethylene — CH_2. For fire protection, it's wrapped two times in aluminum tape and Nomex [flame-retardant fabric]." The delivered unit, assembled in JSC clean rooms, costs less than $100,000.

Helms' temporary sleep station was an empty rack position in the Destiny lab module. The shielding was wrapped up as a 150-pound "brick" for launch, then unfolded in orbit to provide shielding on three sides. Air ventilation and crew egress requirements restrict how much of the sleep area can be enclosed. Cucinotta says NASA is negotiating with the Russian Space Agency to add shielding to the sleep stations in the Zarya module, and with the Italian Space Agency to upgrade Node 3 to serve as a habitat.

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